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TITLE: DATA PROCESSING APPARATUS AND METHOD

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# DATA PROCESSING APPARATUS AND METHOD

## Field of Invention

The present invention relates to encoding data processing apparatus and methods, which are arranged to introduce code words into versions of material items. In some applications the code words are used to uniquely identify the material items.

Correspondingly, the present invention also relates to data processing apparatus and methods operable to detect one or more code words, which may be present in a material item.

## Background of the Invention

A process in which information is embedded in material for the purpose of identifying the material is known as watermarking. Watermarking can provide a facility for identifying a recipient of a particular version of the material. As such, if the material is copied or used in a way, which is inconsistent with the wishes of the distributor of the material, the distributor can identify the material version from the identification code word and take appropriate action.

In this description, an item of material, which is copied or used in a way, which is inconsistent with the wishes of the originator, owner, creator or distributor of the material, will be referred to for convenience as an offending item of material or offending material. The material could be any of video, audio, audio/video material, software programs, digital documents or any type of information bearing material.

Any watermarking scheme should be arranged to make it difficult for users receiving copies of the same material to collude to either mask a watermark code word or alter a watermark code word. A watermarking scheme should therefore with high probability identify a marked material item, which has been the subject of a collusion attack. This is achieved by identifying a code word recovered from the offending material. Conversely, there should be a low probability of not detecting a code word when a code word is present (false negative probability). In addition the probability of falsely detecting a user as guilty of taking part in a collusion attack, when this user has not taken part, should be as low as possible (false positive probability).

US Patent Serial No. 5, 664, 018 discloses a watermarking process in which a plurality of copies of material items are marked with a digital watermark formed from a code word having a predetermined number of coefficients. The watermarked material item is for example an image. The apparatus for introducing the watermark transforms the image into the Discrete Cosine Transform (DCT) domain. The digital watermark is formed from a set of randomly distributed coefficients having a normal distribution. In the DCT domain each code word coefficient is added to a corresponding one of the DCT coefficients. The watermarked image is formed by performing an inverse DCT. A related publication entitled "Resistance of Digital Watermarks to Collusion Attacks", by J. Kilian, F. T. Leighton et al, published by MIT, July 27, 1998, provides a detailed mathematical analysis of this watermarking process to prove its resistance to attack. Co-pending UK patent applications 0129865.2, 0129841.3, 0129840.5, 0129907.2 and 0129836.3 disclose encoding and detecting apparatus and methods which aim to provide a practical watermarking system, which utilises code words having coefficients which are randomly distributed as proposed in US 5,664,018.

**Summary of Invention**

An object of the present invention is to provide an improvement in the registration between the suspected version and the original version of a material item.

According to the present invention there is provided a detecting data processing apparatus operable to determine whether one or more code words of a predetermined set of code words is present in a suspected version of a material item. The apparatus comprises a registration processor operable to associate samples of the suspected version with samples of a copy of the original material item, a recovery processor and a detection processor. The recovery processor is operable to generate a recovered code word by comparing the registered copy of the original and the suspect material items. The detection processor is operable to detect one or more code words from a correlation between the recovered code word and the code words from the set. The registration processor is operable to form at least one reduced-bandwidth-version of the material item and to associate the suspected version and the copy of the material

item in accordance with a comparison between the reduced-bandwidth-versions of the suspected version and the original material item.

The present invention aims to provide an improvement in the registration between the suspected version and the original version of a material item. The registration of the suspected version and the original version of a material item is typically required in order to correctly recover a code word from the suspected version. As explained in co-pending UK patent application 0129907.2, the code word is recovered from the suspected material item by comparing respective samples of the suspected version with the samples of the original material item. However, by providing a registration processor to associate the samples of the suspected version and the original version of the material items, the code word will be more likely to be correctly recovered. Accordingly, the likelihood of correctly detecting the code word will be improved, reducing the false negative probability. For material items such as video recordings of motion picture films, a substantial number of samples may need to be associated in order to effect the registration process. As a result, the registration process may be time consuming or at least computationally difficult. However, by forming reduced-bandwidth-versions of the suspected version and the original version of the material items, a corresponding reduction in the time taken to perform the registration process is provide in accordance with the bandwidth reduction.

The registration processor may be operable in some embodiments to generate a plurality of reduced-bandwidth-versions of the suspected and the copy of the original material items in accordance with a plurality of levels. Each level corresponds to an increasing reduction in the bandwidth of the suspected and original material items. Advantageously, the association of the suspected version and the copy of the original version may be determined in accordance with a nested alignment process. The nested alignment process is provided by comparing reduced-bandwidth-versions of the suspected and original material items on a lower bandwidth level, determining any misalignment and making an adjustment to the reduced bandwidth suspected and original material items at the next lowest level according to the determined misalignment and so on. As a result a time to perform the registration process can be reduced, whilst the accuracy of the registration process is increased, as a result of the progressively increased resolution of the material items being compared.

In preferred embodiments, the suspected version is assumed to have been formed by combining a code word with part of the bandwidth of the original material item. The detecting data processing apparatus includes a bandwidth adaptation processor operable in combination with the recovery processor to form reduced-bandwidth-versions of the suspected version and the original versions of the material items, or a difference between the suspected and original material items. The registration processor is operable in combination with the bandwidth adaptation processor to perform the association as part of the bandwidth reduction. As such, although the reduced-bandwidth-versions of the suspected and original material items or their difference is required to recover the code word the registration process is integrated with the bandwidth reduction. For example, the code word may have been introduced into at least one of the temporal or spatial low bandwidth of the suspect material item and correspondingly the bandwidth adaptation processor is operable to perform the bandwidth reduction at least one of temporally or spatially. The plurality of reduced-bandwidth-versions may therefore be formed temporally or spatially.

Various further aspects and features of the present invention are defined in the appended claims.

**Brief Description of Drawings**

Embodiments of the present invention will now be described by way of example only with reference to the accompanying drawings, where like parts are provided with corresponding reference numerals, and in which:

Figure 1 is a schematic block diagram of a data processing apparatus which operates as a watermark encoder;

Figure 2 is a schematic block diagram of a detecting data processing apparatus;

Figure 3A is a representation of an original image, Figure 3B is a representation of a marked image and Figure 3C is the marked image after registration;

Figure 4 is a graphical representation of an example correlation result for each of a set of $N$ code words;

Figure 5 is a schematic block diagram of an encoding data processor according to an embodiment of the invention;

Figure 6 is a schematic block diagram of a temporal up-sampler forming part of the encoding data processor shown in Figure 5;

Figure 7 is a schematic block diagram of a spatial up-sampler forming part of the encoding data processor shown in Figure 5;

Figure 8 is a schematic block diagram of a spatial sub-sampler forming part of the data processing apparatus shown in Figure 5;

Figure 9 is a schematic block diagram of a temporal sub-sampler forming part of the data processing apparatus shown in Figure 5;

Figure 10 is a schematic block diagram of a detecting data processing apparatus, which operates to detect watermark code words in the marked material items;

Figure 11 is a representation of spatially sub-sampled video frames having three levels of sub-sampling to illustrate a nested alignment process according to an embodiment of the invention; and

Figure 12 is a flow diagram representing the operation of the registration processor according to the nested alignment process embodying the invention.

## Description of Preferred Embodiments

### *Watermarking System Overview*

An explanation of a watermarking technique utilised by embodiments of the present invention will now be described with reference to protecting, for example video images. The number of users to which the video images are to be distributed determines the number of copies. A watermark code word is added to each copy which identifies the copy assigned to one of the users.

Video images are one example of material, which can be protected by embedding a digital code word. Other examples of material, which can be protected by embedding a code word, include software programs, digital documents, music, audio signals, audio/visual material, multi-media content and any other information-bearing signal.

An example of an encoding image processing apparatus, which is arranged to introduce an identification code word into a copy of an original image, is shown in Figure 1. An original image *I* is received from a source and stored in a frame store 1. This original image is to be reproduced as a plurality of water marked copies, each of which is marked with a uniquely identifiable code word. The original image is passed to a Discrete Cosine Transform (DCT) processor 2, which divides the image into 8 x 8 pixel blocks and forms a DCT of each of the 8x8 pixel blocks. The DCT processor 2 therefore forms a DCT transformed image *V*.

In the following description the term "samples" will be used to refer to discrete samples from which an image (or indeed any other type of material) is comprised. The samples may be luminance samples of the image, which are otherwise, produced from the image pixels. Therefore, where appropriate the terms samples and pixels are interchangeable.

The DCT image *V* is fed to an encoding processor 4. The encoding processor 4 also receives identification code words from an identification code word generator 8.

The code word generator 8 is provided with a plurality of seeds, each seed being used to generate one of the corresponding code words. Each of the generated code words may be embedded in a copy of the original image to form a watermarked image. The code word generator 8 is provided with a pseudo random number

generator. The pseudo random number generator produces the code word coefficients to form a particular code word. In preferred embodiments the coefficients of the code words are generated in accordance with a normal distribution. However, the coefficients of the code word are otherwise predetermined in accordance with the seed, which is used to initialise the random number generator. Thus, for each code word there is a corresponding seed which is stored in a data store 12. Therefore, it will be understood that to generate the code word $X^i$, $seed_i$ is retrieved from memory 12 and used to initialise the random number generator within the code word generator 8.

In the following description the DCT version of the original image is represented as $V$, where;

$$V = \{v_i\} = \{v_1, v_2, v_3, v_4, \ldots\ldots\ldots\ldots v_N\}$$

and $v_i$ are the DCT coefficients of the image. In other embodiments the samples of the image $v_i$ could represent samples of the image in the spatial domain or in an alternative domain.

Each of the code words $X^i$ comprises a plurality of $n$ code word coefficients, where;

$$X^i = \{x_j^i\} = \{x_1^i, x_2^i, x_3^i, x_4^i, \ldots\ldots\ldots\ldots x_n^i\}$$

The number of code word coefficients $n$ corresponds to the number or samples of the original image $V$. However, a different number of coefficients is possible, and will be determined in dependence upon a particular application.

A vector of code word coefficients $X^i$ forming the $i$-th code word is then passed via channel 14 to the encoder 4. The encoder 4 is arranged to form a watermarked image $W_i$ by adding the code word $X^i$ to the image $V$. Effectively, therefore, as represented in the equation below, each of the code word coefficients is added to a different one of the coefficients of the image to form the watermark image $W_i$.

$$W^i = V + X^i$$

$$W^i = v_1 + x_1^i, v_2 + x_2^i, v_3 + x_3^i, v_4 + x_4^i, \ldots\ldots\ldots\ldots, v_n + x_n^i$$

As shown in Figure 1, the watermarked images $W_i$ are formed at the output of the image processing apparatus by forming inverse DCT of the image produced at the output of the encoding processor 4 by the inverse DCT processor 18.

Therefore as represented in Figure 1 at the output of the encoder 4 a set of the watermarked images can be produced. For a data word of up to 20-bits, one of 10 000 000 code words can be selected to generate 10 million watermarked $W_i$ versions of the original image $I$.

As shown in Figure 1, the DCT processor 2, the encoding processor 4 and the inverse DCT processor 18 form a watermark encoder 120. The watermark encoder 120 also forms part of a data processing apparatus shown in Figure 5, which will be explained shortly. Furthermore the data store 12 and the code word generator 8 form a watermark generator 116, which also appears in Figure 5.

Although the code word provides the facility for uniquely identifying a marked copy $W_i$ of the image $I$, in other embodiments the 20 bits can provide a facility for communicating data within the image. As will be appreciated therefore, the 20 bits used to select the identification code word can provide a 20 bit pay-load for communicating data within the image $V$.

The encoding image processing apparatus which is arranged to produce the watermarked images shown in Figure 1 may be incorporated into a variety of products for different scenarios in which embodiments of the present invention find application. Generally the distribution of the watermarked images produced by the encoding image processing apparatus shown in Figure 1 is represented by a distribution cloud 19.

***Detecting Processor***

A detecting image processing apparatus which is arranged to detect one or more of the code words, which may be present in an offending marked image is shown in Figure 2. Generally, the image processor shown in Figure 2 operates to identify one or more of the code words, which may be present in an offending copy of the image.

The offending version of the watermarked image $W'$ is received from a source and stored in a frame store 20. Also stored in the frame store 24 is the original version of the image $I$, since the detection process performed by the image processor requires the original version of the image. The offending watermarked image $W'$ and the

original version of the image are then fed via respective connecting channels 26, 28 to a registration processor 30.

As already explained, a suspect version of the image $W'$ may have been produced by photographing or otherwise reproducing a part of the watermarked image $W^i$. As such, in order to improve the likelihood of detecting the identification code word, the registration processor 30 is arranged to substantially align the offending image with the original version of the image present in the data stores 20 and 24. The purpose of this alignment is to provide a correspondence between the original image samples $I$ and the corresponding samples of the watermarked image $W^i$ to which the code word coefficients have been added.

The effects of the registration are illustrated in Figure 3. In Figure 3 an example of the original image $I$ is shown with respect to an offending marked version of the image $W'$. As illustrated in Figure 3, the watermarked image $W'$ is offset with respect to the original image $I$ and this may be due to the relative aspect view of the camera from which the suspect version of the watermarked image was produced.

In order to recover a representation of the code word coefficients, the correct samples of the original image should be subtracted from the corresponding samples of the marked offending image. To this end, the two images are aligned. As shown in Figure 3, the registered image $W''$ has a peripheral area $PA$ which includes parts which were not present in the original image.

As will be appreciated in other embodiments, the registration processor 30 may not be used because the offending image $W'$ may be already substantially aligned to the originally version of the image $I$, such as, for example, if the offending version was downloaded via the Internet. Accordingly, the detecting image processor is provided with an alternative channel 32, which communicates the marked image directly to the recovery processor 40.

The registered image $W''$ is received by a recovery processor 40. The recovery processor 40 also receives a copy of the original image $I$ via a second channel 44. The registered image $W''$ and the original image $I$ are transformed by a DCT transform processor 46 into the DCT domain. An estimated code word $X'$ is then formed by

subtracting the samples of the DCT domain marked image $V'$ from the DCT domain samples of the original image $V$ as expressed by the following equations:

$$X' = V' - V$$
$$= v_1' - v_1, v_2' - v_2, v_3' - v_3, v_4' - v_4, \ldots\ldots\ldots, v_n' - v_n,$$
$$= x_1', x_2', x_3', x_4', \ldots\ldots\ldots\ldots\ldots\ldots x_n'$$

The output of the recovery processor 40 therefore provides, on a connecting channel 50, an estimate of the coefficients of the code word which is to be identified. The recovered code word $X'$ is then fed to a first input of a correlator 52. The correlator 52 also receives on a second input the regenerated code words $X^i$ produced by the code word generator 54. The code word generator 54 operates in the same way as the code word generator 8 which produces all possible code words of the set, using the predetermined seeds which identify uniquely the code words from a store 58.

The correlator 52 forms $n$ similarity $sim(i)$ values. In one embodiment, the similarity value is produced by forming a correlation in accordance with following equation:

$$sim(i) = \frac{X^i \cdot X'}{\sqrt{X^i \cdot X'}} = \frac{x_1{}^i \cdot x_1' + x_2{}^i \cdot x_2' + x_3{}^i \cdot x_3' + \ldots\ldots + x_n{}^i \cdot x_n'}{\sqrt{x_1{}^i \cdot x_1' + x_2{}^i \cdot x_2' + x_3{}^i \cdot x_3' + \ldots\ldots + x_n{}^i \cdot x'}}$$

Each of the n similarity values $sim(i)$ is then fed to a detector 60. The detector 60 then analyses the similarity values $sim(i)$ produced for each of the n possible code words. As an example, the similarity values produced by the correlator 52 are shown in Figure 4 with respect to a threshold $TH$ for each of the possible code words. As shown in Figure 4, two code words are above the threshold, 2001, 12345. As such, the detecting processor concludes that the watermarked version associated with code word 2001 and code word 12345 must have colluded in order to form the offending image. Therefore, in accordance with a false positive detection probability, determined from the population size, which in this case is 10 million, and the watermarking strength $\alpha$, the height of the threshold $TH$ can be set in order to guarantee the false detection probability. As in the example in Figure 4, if the similarity values produced by the correlator 52 exceed the threshold then, with this false positive probability, the recipients of the marked image are considered to have colluded to form the offending watermarked version of the image $W^i$.

**Bandwidth Adaptive Encoding Data Processor**

An improved encoding data processor according to an embodiment of the invention is shown in Figure 5. As will be explained shortly, the encoding data processor is arranged to introduce a code word into a part of the bandwidth of a material item. In the example embodiment shown in Figure 5, the code word is introduced into a low bandwidth part of a material item such as for example a motion picture film or video recording. As will be explained, this is effected by assuming that the code word corresponds to a low bandwidth part of the material. The bandwidth of the code word is then up-converted to the bandwidth of the material and combined with a copy of the material to form a watermarked version of the material. However in other embodiments the code word may be combined with another portion of the material item bandwidth.

The encoding data processor shown in Figure 5 comprises a bandwidth processor 100 formed from a first adaptation processor 102 and a second adaptation processor 104. A watermark code word generator 106 generates code words, which are fed via a code word processor 108 to the first adapter 102. An original material item is fed from a source 110 to the second bandwidth adaptation processor 104.

The first adaptation processor 102 is operable to increase the bandwidth of the code word to the bandwidth of the material item. The second adaptation processor 104 is operable to form a reduced-bandwidth-version of the original material item, which is fed to a registration processor 112. The registration processor is operable to associated the samples of the reduced-bandwidth-version of the material item with the coefficients of the code word which are to be added to the material item. In order to reduce a likelihood of the code word being perceivable in the material item after the code word has been combined with the material item, the code word coefficients are adapted in accordance with a sensitivity of the material to carry the coefficients. To this end, the samples to which the code word coefficients are to be added by the watermark processor 108, are made available to the watermark processor 108, from the registration processor 112 via a connecting channel 114. Techniques for adapting the code word coefficients in accordance with a sensitivity of the material to carry the coefficients whilst maintaining a predetermined false positive and false negative

detection probability are detailed in co-pending UK patent applications number 0129865.2.

The increased bandwidth version of he code word is fed to a first input 116 of a combining processor 118. To a second input 120 of the combining processor 118, a copy of the original material item is fed. The combining processor is arranged to combine the increased bandwidth version of the code word with the copy of the material item to form a watermarked version 122 of the material item at an output 124. Therefore, in combination, than bandwidth adaptation processor 100 and the combining processor 118 combine the code word with the low frequency components of the material item. As will be appreciated in other embodiments the code word may be combined in another portion of the bandwidth of the material item.

The bandwidth reduction performed by the second adaptation processor 104 should correspond to the bandwidth increase applied by the first adaptation processor 102. As a result, the reduced-bandwidth-version of the material item should have a bandwidth which is substantially the same as the watermark code word. As will be appreciated, by matching the bandwidth reduction applied to the material item to the bandwidth of the code word, the samples of the reduced-bandwidth-version of the material item and the code word coefficients can be associated by the registration processor 112. Accordingly, the watermark processor 108 can adapt the coefficients of the code word in accordance with the sensitivity of the samples to carry the code word. However some embodiments may not include the second adaptation processor 104, the registration processor 112 or the watermark processor 108. Such embodiments would only require the first adaptation processor of the bandwidth processor 100 and the combining processor 118.

As explained above, the first adaptation processor 102 is arranged to increase the bandwidth of the watermark code word, so the that increased bandwidth corresponds to the bandwidth or part of the bandwidth of the material item. There are various techniques for effecting this bandwidth increase. For the example embodiment shown in Figure 5, the bandwidth increase is effected in both the temporal and spatial domains. In other embodiments, the bandwidth increase may be spatially or temporally effected. The first adaptation processor comprises a temporal up-sampler 126 and a spatial up-sampler 128. An example implementation of a temporal up-

sampler 126 is shown in Figure 6 and an example of a spatial up-sampler 128 is shown in Figure 7.

The temporal up-sampler 126 shown in Figure 6 comprises a sample rate increase processor 140 and a low pass filter 142. The sample rate increase processor 140 is arranged to increase the sample rate of the code word by introducing samples between the code word coefficients in accordance with a desired temporal bandwidth increase. The low-pass filter has a pass-band, which corresponds to the temporal bandwidth of the material item. As such by passing the up-sampled version of the code word through the low-pass filter, an interpolation of the code word samples is formed, which has an effect of spreading the temporal bandwidth of the code word across the bandwidth of the material item.

The spatial up-sampler shown in Figure 7 comprises a wavelet forming processor and an inverse wavelet transformer 146. The up-sampler performs an eight times spatial up-sampling by forming the code word into the lowest frequencies sub-band of a second order wavelet transform. The second order wavelet transform is formed by the wavelet forming processor 144. The coefficients of the other sub-bands are set to zero. The inverse wavelet transformer then performs an inverse wavelet transform on the formed wavelet, which has an effect of spatially up-sampling the code word by a factor eight.

Returning to Figure 5, the second adaptation processor which produces the reduced-bandwidth-version of the material item comprises a spatial sub-sampler 132 and a temporal sub-sampler 134. As will be appreciated, there are various techniques for implementing a bandwidth reduction on a data signal. However as explained above the second adaptation processor generates the reduced-bandwidth-version of the original material item in correspondence with the bandwidth increase performed on the code word. Figures 8 and 9 provide block diagrams of example implementations of the spatial and temporal sub-samplers 132, 134.

In Figure 8, the spatial sub-sampler comprises a wavelet transformer 204 and a wavelet selector 206. The spatial sub-sampling is implemented using the wavelet transform. To this end, the wavelet transformer 204 is arranged to generate a second order wavelet transform of the material. The wavelet selector 206 is then arranged to select the lowest frequency wavelet sub-band, setting the wavelet coefficients in the

other sub-bands to zero. This is illustrated in Figure 8, by a representation of a wavelet transform of a video frame 210, formed by the wavelet transformer 204, and an illustration of the wavelet transformed frame 212 formed after processing by the wavelet selector 206. By selecting the lowest frequency wavelet sub-band of a second order wavelet transformed image, a spatially sub-sampled version of the video frame is formed, which has been down-sampled by a factor of eight.

Correspondingly, the temporal sub-sampler 134 illustrated in Figure 8 includes a low-pass filter 220, which functions as an anti-aliasing filter for the temporally sub-sampled material. The bandwidth of the low pass filter is therefore set in accordance with a rate at which the material is to be sub-sampled. For the illustrative example, the temporal sub-sampling rate is four. Accordingly, after the low pass filter 220, a frame selector 222 is operable to select every fourth frame of the material, discarding the other frames, to form the temporally sub-sampled material.

**Detection Data Processor**

As already explained, a code word which is present in a marked version of a material item, can be detected with a predetermined false positive and false negative detection probabilities. The detection data processor illustrated in Figure 2 can be arranged correspondingly to detect whether a code word is present in a suspect material item. However, because the code word has been combined with a low bandwidth component of the material item, some adaptation of the detecting data processor shown in Figure 2 is required. A data detecting processor according to an example embodiment of the invention is shown in Figure 10.

In Figure 10 the suspect material is fed from a store 400 to a spatial bandwidth processor 404. Also fed to the spatial bandwidth processor 404 is a copy of the original source material from a second store 402. The spatial bandwidth processor 404 comprises a first spatial sub-sampler 406 and a second spatial sub-sampler 408. The first and second spatial sub-samplers 404, 406 are arranged to perform spatial sub-sampling at a rate which corresponds to the up-sampling performed by the spatial up-sampler 128 performed by the encoding data processor illustrated in Figure 5. For this example, the spatial sub-sampling rate is one eighth. The spatial sub-samplers 406, 408 can be implemented as illustrated in Figure 7, as explained above. As will be

appreciated the same spatial sub-sampler could be used for both the suspect and the original material versions.

The spatially sub-sampled versions of the suspect and the original material items are receive by a temporal registration processor 410 from connecting channels 412, 414. The temporal registration processor 410 operates to temporally align the suspect and the original material items to the effect that the samples of the original version are correspondingly synchronised to the samples of the suspect version of the material item.

The temporally aligned suspect and original material items are then fed to a temporal bandwidth processor 416. The temporal bandwidth processor 416 includes a first temporal sub-sampler 418 and a second temporal sub-sampler 420, which are arranged to received the temporally aligned suspect and original material items respectively. Temporal sub-sampling is performed by the first and second temporal sub-samplers 418, 420 on the suspect and original material items in correspondence with the temporal up-sampling rate performed by the up-sampler 126 in the encoding data processing apparatus 101 of Figure 5. The temporally and spatially sub-sampled version of the suspect and original material items are then received by a spatial registration processor 422. The spatial registration processor 422 is operable to provide a spatial alignment of the samples of the suspect and the original material items.

The spatial and the temporal bandwidth processors 404, 416 operate to form reduced-bandwidth-versions of the suspect and copy of the original material items. In effect the temporal and spatial registration processors 410, 422 are arranged to associate the samples of the reduced-bandwidth-versions of the suspect and the copy of the original material items. Effectively, therefore a subtracting processor 40′ receives respective samples of the suspect and the original material items to which code word coefficients may have been added. A result of the subtraction is to form a vector of samples $X'$ which represents a recovered code word. The recovered code word $X'$ is then fed to a correlator 52′ which operates in combination with the detector 60′, as already explained with respect to the detecting data processor of Figure 2 to determine whether the recovered code word corresponds to one of the set of code

words. The explanation will, therefore not be repeated here. The detected code word can then uniquely identify a recipient of the offending material item.

The operation of the encoding data processor to adapt the bandwidth of the code word and combine the code word coefficients with the material item represents a linear mathematical process. As a result in alternative embodiments, the detecting data processor may be arranged to subtract the copy of the material item from the suspect material item and then proceed to form a reduced-bandwidth-version of the difference. The reduced-bandwidth-version of the difference is then correlated with the code words from the set of code words to identify if a code word is present in the suspect material as already explained. However, as will be explained in the following paragraphs, forming the reduced-bandwidth-versions of the suspect and the original material items provides an advantage in reducing an amount of processing required to register the suspect and copy of the original material items.

**Improved Registration Process**

Embodiments of the present invention can provide an improved facility for aligning the spatially and temporally sub-sampled versions of the suspect and the copy of the original material item. As such an improvement can be provided in the probability of correctly detecting a code word which is present in an offending material item. The improvement in the registration of the suspect material with the copy of the original material is provided by a multi-stage nested alignment process.

As indicated above, the code word detection processor includes a registration processor comprising the temporal alignment processor 410 and the spatial alignment processor 422. The temporal alignment processor 410 is operable to provide a first temporal alignment of the suspect and original material items. There are various ways in which this can be achieved. For example, for material representing moving images such as a film or a video reproduction, scene changes in the material can be detected from significant changes in the chrominance and/or luminance values between frames of the material. By matching the relative times at which these changes occur, in the suspect and original material items, an estimate of temporal alignment is provided. However as will be appreciated, the suspect material may have a frame rate which differs from the original because the suspect material has been generated in accordance

with a different recording or storage format. As such, in order to identify a scene change which falls between a frame boundary, the suspect material may be further up-sampled by introducing a frames amongst those of the suspect material in accordance with an increased frame rate. Low-pass filtering the up-sampled suspect material provides an interpolated version of the suspect material from which a scene change can be more easily identified.

An advantage is provided by performing temporal alignment after the suspect and original material items have been sub-sampled. This is because the code word has been embedded in the low bandwidth portion to form the marked material items. For this reason, the code word in the material will be less likely to be effected by sub-sampling the suspect and original material items before temporal alignment. Hence the spatial bandwidth processor 404 can sub-sample the suspect and original material items before temporal alignment is performed by the temporal registration processors 406, 408. As a result a time taken to determine the temporal alignment estimate may be substantially reduced, as a result of a reduction in an amount of processing required.

As explained above, after the temporal sub-sampling by the temporal bandwidth processor 416, the spatial registration processor performs a further spatial alignment between the suspect and the original material items. The operation of the spatial registration processor 422 will now be explained in the following paragraphs with reference to Figure 11.

The spatial alignment processor 422 is arranged to form a set of increasingly spatially sub-sampled versions of the suspect and original material items. For the example illustrated in Figure 11, two increasingly spatially sub-sampled versions are formed SSV1, SSV2. For a first example frame C of the suspect material item, two increasingly sub-sampled versions SSV1, SSV2 produce two frames A, B, from a first frame C, of the sub-sampled suspect material version SV. The correspondingly increasingly sub-sampled versions A′, B′ for the two levels SSV1, SSV2 are formed for the original material item frame C′. The spatial alignment processor 422 is then operable to perform a nested spatial alignment process as follows:

(i) The most spatially sub-sampled frames A, A′ of the suspect and original material items are compared;

(ii) A result of the comparison provides an indication of the spatial misalignment between the suspect and original material versions for the most spatially sub-sampled frame A, A′;

(iii) In accordance with any misalignment of the frames A, A′, determined in (ii) an alignment of the next most spatially sub-sampled frames B, B′ is performed;

(iv) The next most spatially sub-sampled frames B, B′ of the suspect and original material items are then compared;

(v) A result of the comparison provides an indication of any spatial misalignment between the suspect and original material versions for the least spatially sub-sampled frames C, C′;

(vi) In accordance with the determined misalignment of the frames B, B′ of the level SSV1, an alignment of the least spatially sub-sampled frames C, C′ is performed;

(vii) Steps (i) to (vi) are repeated for a subsequent set of increasingly sub-sampled frames.

As illustrated in Figure 11, the nested alignment process for increasing levels of spatially sub-sampled frames may not be performed for every frame of the suspect and original material items. The nested alignment of frames may be performed at a rate which corresponds to an amount by which spatial misalignment between the suspect and original material may have occurred. Therefore as illustrated in Figure 11, nested alignment is performed every other frame. It will be appreciated that other rates are envisaged in accordance with a possible rate of change of misalignment such as one in three or one in four frames are aligned in accordance with the nested process.

The nested alignment process for different amounts of spatial sub-sampling has an advantage in both improving the accuracy of the spatial alignment, and reducing an amount of processing which is required to effect spatial alignment. In addition, the application of the code word to the low spatial frequencies reduces the sensitivity of the code word detection process to misalignment.

A flow diagram illustrating the operation of the registration processor is provided in Figure 12. The operation of the registration processor is summarised as follows with reference to Figure 12:

S.1 : The spatially sub-sampled suspect and original material items are received by the temporal alignment processor 410.

S.2: Transitions, scene changes or edit points in the material are detected and temporal alignment is performed.

S.3: The spatially sub-sampled suspect and original material items are temporally sub-sampled.

S.4: For a sample frame of the temporally and spatially sub-sampled suspect and original material items, two further increasingly spatially sub-sampled frames are formed corresponding to two increasingly spatially sub-sampled levels SSV1, SSV2.

S.5: For the lowest level SSV2, comprising the most temporally and spatially sub-sampled frames A, A′, the frames A, A′ are compared and any misalignment determined.

S.6: The frames at the next level of sub-sampling SSV1 are aligned in accordance with the determined misalignment for the most sub-sampled frames A, A′.

S.7: The next most sub-sampled frames B, B′ are compared and any misalignment determined.

S.8: In accordance with the misalignment determined for the next most sub-sampled frames B, B′, the least sub-sampled frames of the suspect and original material items C, C′ are aligned.

The frame alignment process is then repeated for subsequent frames.

Various further aspects and features of the present invention are defined in the appended claims. Various modifications can be made to the embodiments herein before described without departing from the scope of the present invention.